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Item No. 001AN

Technical Progress Report

Development of a Low Noise 10 K J-T Refrigeration System

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1.0 Introduction

This report summarizes work done on Contract No. N00014-86-C-0301 during the period August 31 to October 15, 1990 on the development of a low noise, Joule-Thomson, microminiature refrigeration system.

Progress has been made on the development of the pneumatic compressor drive system which will be used to operate the compressor to determine the compressor lifetime and refrigerator system performance. Work on the refrigerator itself also has progressed well with operation down to 20K now being achieved, and reliably reproduced. Work is underway on the heat exchanger section of the third stage of the refrigerator, the helium stage.

2.0 Compressor: Pneumatic Operation

The relative merits of the pneumatic actuation of the slow compressor, using high and low pressure return gas, were reviewed in the previous report, Technical Progress Report No. 001AM. Implementation of the high pressure return design, is now underway.

A lightweight, compact, oil lubricated pneumatic compressor capable of operating with an input pressure of 4 atm. and an output pressure of 14 atm to drive the refrigeration gas compressor has been tested using air. This resulted in excessive heating of the exhaust gas of the pneumatic compressor. An aircooled heat exchanger was added to the output of the pneumatic compressor, but heating remained a problem. Analysis of the problem in the previous report indicated that a significant improvement in the operation of the pneumatic compressor at this throughput could be had by substituting for air as the working fluid, a gas with a lower value of gamma, i.e. a gas with a smaller ratio of specific heat at constant pressure to that at constant volume. The reason for this is that the temperature rise during adiabatic compression depends exponentially upon the value of $\gamma - 1$, i.e. $T_f = T_i R^{\gamma-1}$, where R is the compression ratio. By using a working gas with a lower value of γ, the high temperature excursions during the compression stroke can be reduced, resulting in a lower average temperature for the out-going gas and more efficient compression.

Initial tests were made using Freon 22 (Chlorodifluoromethane) which has a γ-value of 1.171, but which condenses to a liquid at 40°C at a pressure of 9.5 atm., making it necessary to limit the operating pressure to below this value. With an inlet pressure of 3.4 atm, the temperature of the gas at the pneumatic compressor outlet port increased at a much slower rate (a factor of about 2.4 slower) than that obtained when using air in the compressor, but still climbed, eventually, to an unacceptably high level, probably due to the irreversibility introduced by working so close to the condensation point. This result was encouraging but not conclusive. Further work was needed using Freon 13 with $\gamma = 1.14$ or Freon 14 with $\gamma = 1.15$. These figures should be compared to the value for air of 1.41. A reduction in the temperature rise (under adiabatic conditions) by a factor between three and four should be obtained using Freon 13 or 14.

The pneumatic compressor was then modified to allow it to be filled and sealed for use with these gases as the working fluid. Initial tests with Freon 13 have now been done and these indicate that the heating problem of the compressor has been controlled and that the temperature of the compressor does not now exceed 80° C. It is expected that this maximum temperature will be lowered further by improving the control of the air flow over the pneumatic compressor housing. These results will enable the program to progress to the phase of long term operation testing of the refrigeration gas compressor.

3.0 High Vacuum Test Chamber

A high vacuum, turbo pumped test chamber has been assembled and initial testing has been completed. This vacuum system provides a vacuum of better then 10^{-6} Torr. This will be used for the testing of the hydrogen and helium stages of the ONR refrigerator.

4.0 Refrigerator

Difficulties had been experienced previously in operating some of the refrigerators to their minimum temperature. Upon turning on the hydrogen to the second stage, the nitrogen stage precooler would warm up. This was not a transient effect but resulted in the nitrogen stage remaining at a temperature which was too high to permit the second stage to reach its proper operating temperature. This appeared to be due to inefficiency of the final stage laminar flow heat exchanger in the hydrogen stage. This inefficiency is strongly dependent upon the mass flow through this stage and on the thermal conductivity of the glass interlayer which separates the two counter-flowing gases in the heat exchanger. In the past, difficulty in controlling the gas flow to the required precision had caused wide variations in the performance of otherwise similar coolers. As this difficulty has been brought under control, the importance of using a material of higher thermal conductivity as the interlayer has assumed greater importance. Details and results of work in this area are reported below.

4.1 Fabrication

We have now redesigned the hydrogen stage heat exchanger by increasing the length of the flow path, using a serpentine configuration, and thus have improved its overall efficiency. Refrigerators have been fabricated with these modifications in the long out-flow, laminar-flow heat exchanger and an improvement in the performance of the refrigerator has been observed.

However, a further cause of inefficiency in the hydrogen stage lies in the temperature drop across the glass interlayer between the inflow and the outflow channels. At the lowest temperatures, this becomes important because of the rapid drop in thermal conductivity of the glass as the temperature is reduced and this becomes more important as the mass flow, and hence the heat flow, through this stage is increased. To minimize the effects of this, the interlayer is being fabricated now with 0.006" thick glass and experiments have been made using still thinner, 0.003" microsheet. These latter experiments have indicated that the fusing process must be adjusted to accommodate the use of these thinner glass interlayers. In addition we have attempted to fuse to the glass substrates, interlayers of Kovar, of molybdenum, and of platinum to give a higher conductivity material for the heat transfer between the two gas streams in the lower temperature portions of the refrigerator. The bonding process has been most successful with the use of the platinum foil. Good clean bonds of the 0.001" platinum foil to the solder glass have been obtained and efforts will continue to refine this approach for the fabrication of the refrigerators.

4.2 Test Results

Operation of the two stage refrigerator to a temperature of 20K has now been achieved with the improved hydrogen stage heat exchanger using 99.998% pure nitrogen in the first stage and pumping on the exhaust of that stage to reduce its temperature to approximately 77K, and using 99.999% purity hydrogen in the second stage. Temperatures below the normal boiling point of hydrogen, 20.4K, were achieved by pumping on the exhaust of that stage.

Tests have frequently been hampered by clogging of the hydrogen stage. It was believed that this clogging was due to a high level of impurities in the hydrogen gas source. However, experiments have shown that reproducible, clog-free operation of the refrigerator can be obtained using only 99.99% purity hydrogen and carefully prepared gas filters, rather than the 99.999%, higher purity gas. It is believed, based on recent reports at the Sixth International Cryocooler Conference, held in Plymouth, MA in October 1990, that greater gas purity and improved cooler operation can be obtained using an activated charcoal filter in conjunction with the filters which we have used with these refrigerators in the past. It is concluded that higher purity hydrogen gas will not be required for operation with this refrigerator but that the preparation and purging of the filters must be done with sufficient care to ensure proper operation and that an activated charcoal filter should be added to the purification column. Protocols for these procedures have been prepared. Tests with the activated charcoal filter will be initiated.

4.3 Future Refrigerator Design Objectives

As discussed above, we are now focussing on the use of still thinner glass and metal foil interlayers in the hydrogen and helium stages of the cooler. These are key to the efficient operation of the low temperature stages of the refrigerator and is expected to increase the efficiency of the present cooler by a factor of three. This is an essential step, as well, for the attainment of liquid helium temperatures, where the drop off in thermal conductivity of the glass interlayer becomes even more important. We are focusing also on the life testing of the compressor and the development of better gas filtering technology for use with the refrigerator.

5.0 Personnel

The following persons have been involved in the program:

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Respectfully submitted,

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